www.neimagazine.com

October 2023

NUCLEAR ENGINEERING INTERNATIONAL

Fuel & fuel cycle
Advanced fuels explored

Waste management
Solving the Pu problem

Country profile
A Philippine nuclear future

Safety & security
Conflict & nuclear blackmail

Robotics
Robots go walkies

Lean and mean

A new approach to cut reactor costs

magazine | digital | events

serving the nuclear industry since 1956

Lean methods in nuclear power

The solution to the cost-effective delivery of nuclear power stations is to adopt a modular approach to designing and building them. That means a fundamental rethink on planning and designing new nuclear reactors

By: Tony Roulstone, Nuclear Energy Lecturer, University of Cambridge, Dept. of Engineering, Simon Murray, Founding Member of Acumen7, Gary Fischer, Executive Director Project Production Institute

THE LONG-AWAITED STARTUP OF of Georgia Power's Vogtle nuclear power plant, seven years late and $17bn over budget is a sobering reminder of the perils involved with nuclear power plant investments. Clearly, nuclear power has a construction cost and long build schedule problem using the current approach. However, out of necessity nuclear power is returning to the energy agenda because of the challenges of climate change and a refreshed understanding of the need for energy security.

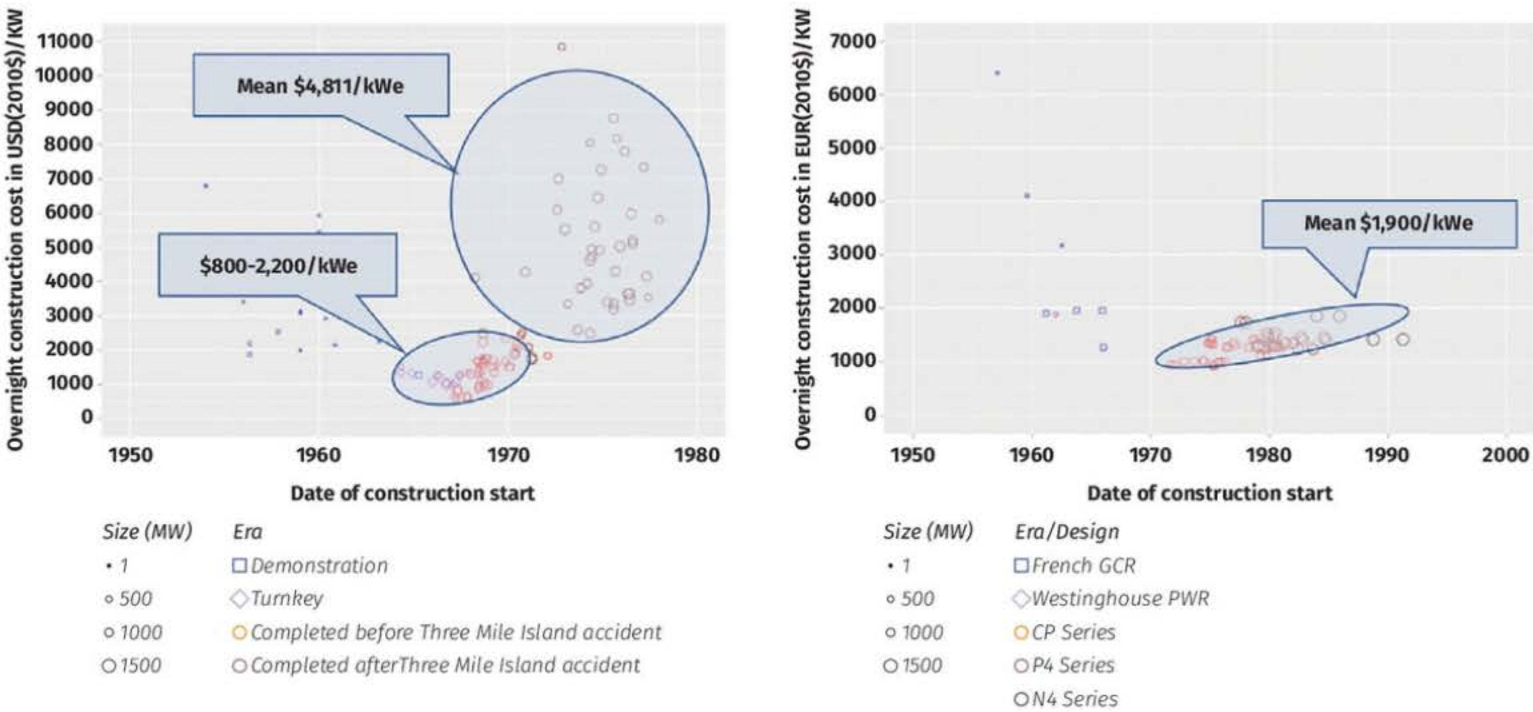
In the UK, for example, successive governments have tried to solve the cost/schedule problem using international tendering to procure and finance large new one-off power stations like Hinckley Point C, Moorside and Wylfa. Suppliers have spent billions developing unique designs, preparing their offers and engaging in years of negotiations with the government over who will bear the risks of construction delays and cost overruns. These projects have either collapsed in negotiations over funding or, as in the case of Hinckley Point C, have been funded by foreign governments that have underwritten the risks in return for guaranteed prices for the electricity they will generate. As a result, consumers will pay high prices for this electricity for many years to come.

This is not a viable solution. The cost/schedule problem can only be addressed by taking a fresh programme approach, adopting modern production methods that are commonplace elsewhere but not applied in the nuclear industry and by creating production systems or optimising existing ones that profit from series build as against one-off projects and drive efficiency throughout the supply chain.

Reducing reactor costs

In his recent book *How Big Things Get Done*, (Macmillan 2023), Professor Bent Flyvbjerg of the Said Business School at Oxford showed that the UK is not alone in finding it difficult to deliver new nuclear power stations. Drawing on a database of more than 1,000 infrastructure projects from around the world, he calculated that nuclear power stations are amongst the least predictable with average cost overruns of 120% and average delays of 65% of the original schedules. He concluded that this is caused by the fact that most of these are large and complex projects built to unique designs. The projects take many years to complete so there are few opportunities for the teams to learn from project to project and many opportunities for projects to be impacted by unforeseen events.

Right:
Vogtle was both late and over budget, illustrating the perils of nuclear development
Photo credit: Georgia Power Company



Above, figure 1: **US and French nuclear capital cost experience** Source: Lovering (2016)

These conclusions are supported by data from the construction of fleets of nuclear power stations in the USA and France in the 1980s, as reported by Lovering et al in 2016 in their work on historical construction costs of global nuclear power reactors. The US built some fifty reactors using many different vendors, constructors and designs. At about the same time, France built about the same number of reactors based on a design provided by a single US vendor with direction from the centre and stable construction teams. The results summarised in Figure 1 show that for projects built in the 1970s and 1980s, the French power stations cost on average 60% less than those built in the US and were delivered as much as three years earlier.

The UK Energy Technology Institute in their Nuclear Cost Drivers Project, CleanTech Catalyst & Lucid Strategy for UK, has highlighted more recent examples of good practice in nuclear power stations built in Japan and Korea that used standard designs and lean construction ideas. Their improved cost and schedule outcomes were similar to France in 1980s. These countries are now the benchmarks for nuclear construction worldwide. The difference between these benchmark projects and recent experiences in the UK, lies in how the projects are designed and procured. When programmes of new power stations are advanced project by project, the result is usually a series of designs that are unique in detail, each project being built by a different team of suppliers and contractors. Instead, efficiency and economy can come from building the same design over and over again using the same teams.

Flyvbjerg argues that the solution to the cost-effective delivery of nuclear power stations is to adopt a modular approach to designing and building them. If power stations consisted of a series of small modular reactors, each reactor would be cheaper and could be built faster, delivering power to the grid and revenues to the investors in less time. And if each small modular reactor (SMR) was built to a standard design using standard components made in factories, the process would be more efficient and more predictable. The critical step would be to advance programmes of several SMRs so that the successful vendors could invest in stable supply chains and modern production systems enabling them to learn from project to project and deliver continuous improvements in performance.

SMRs have better potential for modularisation because of their smaller size and modularisation has the potential to reduce overall labour costs and schedule duration. But its success depends on the standardisation of the design, the supply chain, and the construction process. The size of the benefit of modularisation depends on the ability to break the design and its systems down into modules that can be fabricated, transported and assembled in-situ. A lesson from industries where modularisation has been used is the importance of production modelling to design the optimal overall production system including what to modularise and where to do the work. Two key decisions that will greatly influence the ultimate outcome.

Taken together, the productivity improvements from off-site manufacture and the economic effects of reducing the length of build schedules on capital costs – measured as the total cost of construction including interest during construction (TCIC) @7.8% pa – can be assessed. They show the baseline is a non-modular 'stick-built' system, with grades of increasing degree of modularisation (DoM). First, there is the effect of economies of scale – as reactor size reduces, construction cost increases due to the unwinding

Below: **French nuclear development followed a more standardised design, revealing cost savings**

of economies of scale. These cost increases can be offset through standardisation, modularisation and production learning. But it is clear, if SMRs are stick-built they will cost more than large reactors. SMRs need modern construction methods to compete.

Furthermore, if the programme contained sufficient projects, nuclear power plant unit cost would reduce over time through production learning and the electricity they generated could be as low as $70-80/MWh, competitive with renewable energy.

Optimising production

Modular designs using standard components are important, but it is the ability to design/optimise and control production system that brings it together and delivers the improvements in performance. This approach has been used for decades to improve the performance of designing and building large capital goods from ships and aircraft to trucks and cars. But before applying it to a programme of SMRs, it is important to understand how it differs from the project management systems that are presently used to deliver nuclear power stations.

Table 1 summarises the principal characteristics of traditional project management and a production management when applied to large infrastructure projects. It is based on a study into the application of production management to construction that was carried out by Anglian Water with support from Heathrow and National Highways in 2019. The study identified the six key features of a production system that are used to make this comparison.

This approach is not new. In 1995, BAA Plc developed a production system to deliver the new Terminal 5 at Heathrow. Using long-term relationships with their suppliers, standard components, computer aided production engineering and production management, BAA completed the new terminal on time and close to the budget. The critical feature of BAA's approach was that for six years before the start of construction in 2002, they used their ongoing investment programme at their airports to develop their supply chain, the production system and their own management team. Subsequently, Anglian Water adapted the approach to deliver a large part of their investment programme making extensive use of modular designs and standard components. According to the Institution of Civil Engineers 2017 report 'From Transactions to Enterprises – A new approach to delivering high performing infrastructure,' over a period of 10 years, they reduced the unit costs of their infrastructure by 30%.

Nuclear power can best address its serious and persistent cost and build schedule problems by adopting a programmatic approach, repetitively building of standard nuclear power plants that have been designed for modular construction, together with investment in series production facilities. Adopting these methods will allow nuclear power to regain competitiveness, allowing it to play a significant role in many countries in addressing climate change.

The key to making these process changes and delivering attendant benefits lies with transforming the mind-set of the nuclear industry from one project at a time, to a series of projects delivered by a production system. Both because the history of the industry and the experience of nuclear project construction managers this will not be easy but is essential if we want nuclear to play a meaningful role in the future energy equation. ■

Table 1 – Project management vs production system

	Project management	Production management
Product Development	Unique project designs completed before the supply chain is in place. Suppliers do detailed engineering during project delivery.	Standard designs for a series of projects done with the suppliers. Engineering done by the suppliers working together before construction begins.
Process Development	Processes for manufacture and assembly developed by individual suppliers	Processes developed with the product by the integrated team of suppliers.
Supply and Logistics	Each supplier responsible for their own supply and logistics.	Supply and logistics integrated with the process and provided for all suppliers.
Organisation And Culture	Fragmented organisation held together by contractual commitments. A new organisation for every project. Every supplier working to optimise their own outcomes.	Integrated organisation held together by commitments to improve performance. The same organisation and supply chain working together and learning from project to project. The whole organisation working together to outperform their targets.
Information Architecture	Each supplier holds their own information about design and production and guards it for fear of it being used against them.	Common systems providing information about design and production that can be accessed in real time by all suppliers.
Governance and metrics	Vendor's commercial managers coordinate the work through the sub-contracts with suppliers. Objective – to deliver a project on time and budget.	An alliance board drawn from the vendor and the suppliers manages the team. Objective – to deliver a series of projects faster, cheaper and predictably.
Execution	Heavily focused on scheduling, contracting strategy and management, risk management and project controls.	Map, model and control the production system. Uses the five levers of production systems performance – product design, process design, capacity, inventory and variability.